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Short Communication

Interaction between ostracods and anurans: a review and new records in Brazil

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Both ostracods and amphibians are able to colonize a wide variety of freshwater environments (Balian *et al.* 2008, Martens *et al.* 2008, Ottonelo and Romano 2011). However, unlike amphibians, ostracods also are widely distributed in marine environments (Coimbra and Bergue 2011). The first fossil records of ostracods are dated from the Ordovician Period and, in the Carboniferous Period, these crustaceans began to colonize freshwater environments (Coimbra and Bergue 2011). Ostracods are found in all types of aquatic environments, such as lakes, rivers, and humid soils of tropical forests and phytotelmata (Pinto and Purper 1970). Like ostracods, some species of anurans are associated with phytotelmata. For example, some anurans use bromeliads throughout their life cycle (bromeligenous), whereas others occupy phytotelmata, using them for shelter and foraging places, but do not reproduce in them (bromelicolous) (Peixoto 1995).

The microhabitats formed by the accumulation of water and debris in the bromeliads maintain diverse invertebrate communities (Richardson 1999, Sabagh *et al.* 2012). Among invertebrates, non-marine ostracods typically are found in this kind of environment (Müller 1879, Lopez *et al.* 2002). The success of ostracods in non-marine environments reflects the resilience of the group and its use of other organisms, such as mammals (Lopez *et al.* 2002), birds (Green and Figuerola 2005), reptiles, and amphibians (Lopez *et al.* 2005) as vectors for dispersion.

Phoresy is a type of commensal interaction between two species, in which one organism acts as a vector for the dispersion of another, with no detrimental effects on either organism (Houck and O'Connor 1991). Ecologically, bromeliads

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function as "islands," representing disconnected freshwater habitats for non-marine ostracods (Frank and Lounibos 1987, Sabagh and Rocha 2014, Lantyer-Silva *et al.* 2016). Given the use of bromeliads by some species of anurans, the frogs are used by ostracods as phoretic vectors (Lopez *et al.* 2005, Sabagh *et al.* 2011). However, such interactions are poorly documented and may not be noticed owing to the small size of these invertebrates. Herein we present five new records of this phoresy between ostracods and four anuran species from four localities in southeastern Brazil, and provide a list of all neotropical amphibians recorded in these relationships.

During fieldwork at localities associated with the Dacnis Project (23.4627° S, 45.1329° W, WGS-84; 37 m a.s.l.) in municipality of Ubatuba and state of São Paulo (Brazil), we found two species of anurans with ostracods on their bodies. The first interaction was recorded on 15 July 2015; the toad *Dendrophryniscus brevipollicatus* Jiménez de la Espada, 1870 (Bufonidade) had an individual of *Elpidium* sp. (Crustacea, Ostracoda) attached to its back, close to its head (Figure 1A). The second interaction was on 09 September 2015 at the same locality. The treefrog *Fritziana mitus* Walker, Wachlevski, Nogueira da Costa, Nogueira-Costa, Garcia, and Haddad, 2018 (Hemiphractidae) had three individuals of *Elpidium* sp. (Crustacea, Ostracoda) attached to its flanks near its legs (Figure 1B). We found both anurans in the central tank of bromeliads.

On 15 August 2015 in the Alcatrazes Archipelago (24.1051° S, 45.6974° W, WGS-84; 134 m a.s.l.), located in the Atlantic Ocean, about 3500 m of the municipality of São Sebastião in state of São Paulo (Brazil), we recorded one individual of *Ololygon alcatraz* (Lutz, 1973) (Hylidae) inside a bromeliad with five ostracods attached to its trunk, foot, and tibia (Figure 1C).

In the shrubs around the "Lago da Mata" area on the campus of Universidade do Vale do Paraíba (UNIVAP) (23.2084° S, 45.9701° W, WGS-84; 591 m a.s.l.) in the municipality of São José dos Campos and state of São Paulo (Brazil), we found a hylid frog, *Scinax crospedospilus* (Lutz, 1925), with two *Elpidium* sp. attached to its flanks close to its head and legs (Figure 1D) on 21 October 2015. We found the same interaction between these species on 08 January 2018 in the area of the Dacnis Project in São Francisco Xavier (22.8744° S, 45.9306° W, WGS-84; 884 m a.s.l), a district of the municipality of São José dos Campos in the state of São Paulo (Brazil). Here, we found seven *Elpidium* sp. attached to the flanks near the legs of a *S. crospedospilus.* Both localities were close to a flooded area where we recorded *S. crospedospilus* calling from inside a bromeliad.

All the voucher specimens were deposited in collections (Appendix I). We did not collect the specimen of *O. alcatraz* or the ostracods found on that individual. The species is the only one occurring on the island and is "Critically Endangered" according to IUCN criteria (Rodrigues and Cruz 2004). Ostracods were identified with the descriptions of Pinto and Jocqué (2013) and Pereira (2013). Despite keys to species of *Elpidium,* we only identified them to the genus, because there are records of cryptic diversity and undescribed species (Little and Herbet 1996).

In addition to the new interactions described above, we performed an exhaustive search of the literature for studies that reported interactions between ostracods and amphibians in the neotropics. We also used "Google Scholar" to locate papers published through October 2019 with the combination of the following keywords: "ostracods," "Amphibia," "phoresy," and "interaction." Amphibian nomenclature is consistent with that of Frost (2019). The publications then were filtered to include only those dealing with neotropical amphibians.

In total, we tallied 20 species of amphibians that interact with ostracods in 13 localities (Table 1). All interactions were observed in Brazil and the ostracods were identified as *Elpidium* sp. The interaction was only recorded for anurans. Hylidae had the largest number of records, with

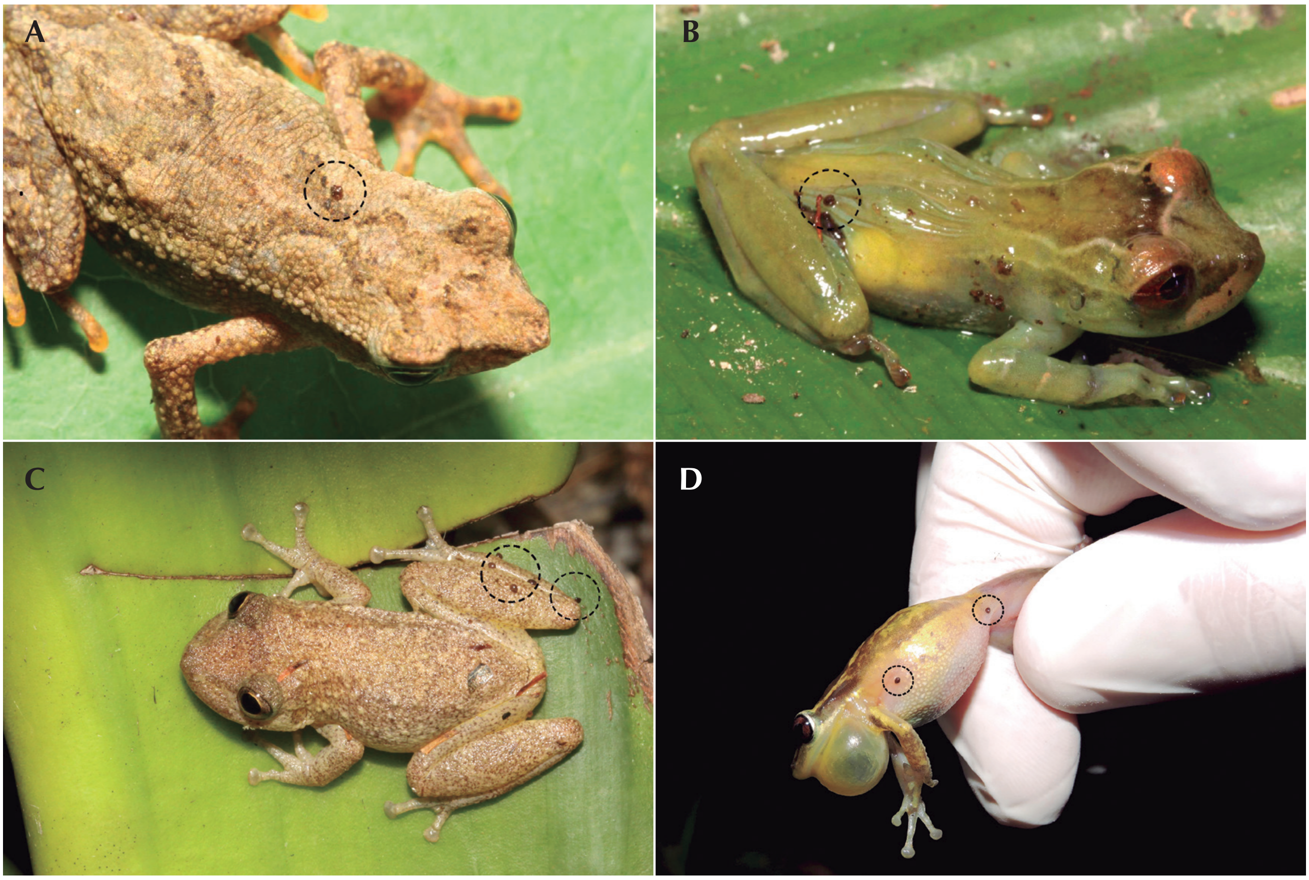

Figure 1. Interaction between ostracods and anurans of four species in three families. (**A**) *Dendrophryniscus brevipollicatus* (Bufonidae) had an individual of *Elpidium* sp. (**B**) The treefrog *Fritziana mitus* (Hemiphractidae) with one individual of *Elpidium* sp. (**C**) The treefrog *Ololygon alcatraz* (Hylidae) had five individuals of *Elpidium* sp. (**D**) the treefrog *Scinax crospedospilus* (Hylidae) had two individuals of *Elpidium* sp. Dashed circle indicates places with ostracods attached.

16 species, followed by Hemiphractidae with 2, and Cycloramphidae and Bufonidae with one each.

Prior records of interactions between ostracods and amphibians are mainly from coastal regions (e.g., Lopez *et al.* 2002, 2005, Sabagh and Rocha 2014) between elevations from 0–963 m a.s.l. The two records of ostracods associated with *Scinax crospedospilus* in the Mantiqueira Mountains at two different localities (Table 1) are the the farthest inland at approximately 80 km from the coast.

Our results show that ostracods are mainly associated with arboreal frogs that use bromeliads. The only species with adherent ostracods that is not arboreal is *Thoropa miliaris* (Spix, 1824) (Sabagh and Rocha 2014). This species usually is found in rocky areas in forests or at the forest edge; the frog deposits its eggs on stones covered by a film of fresh water (Bokermann 1965). *Thoropa miliaris* has been reported to be bromelicolous because the frogs use bromeliads as shelter (Lacerda *et al.* 2009, Pertel *et al.* 2010, Sabagh and Rocha 2014); thus, the species may be a potential disperser of ostracods among aquatic environments.

We observed two populations of *Scinax crospedospilus* calling and sheltering in bromeliads; however, we found neither tadpoles

Table 1. Literature records of phoretic behavior in Brazilian anurans and ostracods and new records of this behavior.

Anuran species	Study area	Altitude (m a.s.l.)	Municipality, Brazilian state	References to the first record
Bufonidae				
Dendrophryniscus brevipollicatus	Projeto Dacnis	37	Ubatuba, São Paulo	This study
Cycloramphidae				
Thoropa miliaris	Parque Estadual Serra da Tiririca	145	Niterói, Rio de Janeiro	Sabagh and Rocha 2014
	MoNa Morro da Urca e Pão de Açúcar	0	Rio de Janeiro, Rio de Janeiro	Sabagh and Rocha 2014
Hemiphractidae				
Fritziana goeldii	Parque Nacional Serra dos Órgãos	963	Teresópolis, Rio de Janeiro	Lopez *et al.* 2005
Fritziana mitus	Projeto Dacnis	37	Ubatuba, São Paulo	This study
Hylidae				
Aparasphenodon brunoi	Barra de Maricá	6	Rio de Janeiro, Rio de Janeiro	Lopez *et al.* 2005
	Parque Nacional da Restinga de Jurubatiba	9	Macaé, Rio de Janeiro	Lopez *et al.* 2005
Aparasphenodon arapapa	Reserva Natural Boa União	95	Ilhéus, Bahia	Lantyer-Silva *et al.* 2016
Aplastodiscus arildae	Parque Nacional Serra dos Órgãos	963	Teresópolis, Rio de Janeiro	Lopez *et al*, 2005
Boana albomarginata	Grumari	10	Rio de Janeiro, Rio de Janeiro	Sabagh *et al.* 2011
Boana semilineata	Parque Nacional da Restinga de Jurubatiba	9	Macaé, Rio de Janeiro	Lopez *et al.* 2005
Dendropsophus decipiens	Alto da Buchada	200	São Lourenço da Mata, Pernambuco	Araújo *et al.* 2019
Ololygon alcatraz	Ilha dos Alcatrazes	134	São Sebastião, São Paulo	This study
Ololygon littorea	Parque Estadual Serra da Tiririca	145	Niterói, Rio de Janeiro	Sabagh *et al.* 2011
Ololygon perpusilla	Barra de Marica	6	Rio de Janeiro, Rio de Janeiro	Lopez *et al.* 2002
	MoNa Morro da Urca e Pão de Açúcar	0	Rio de Janeiro, Rio de Janeiro	Sabagh *et al.* 2011

Table 1 - *Continued.*

Anuran species	Study area	Altitude (m a.s.l.)	Municipality, Brazilian state	References to the first record
Scinax crospedospilus	Lago da Mata (Campus UNIVAP)	591	São José dos Campos, São Paulo	This study
	Projeto Dacnis (SFX)	884	São Francisco Xavier, São Paulo	This study
Scinax auratus	Alto da Buchada	200	São Lourenço da Mata, Pernambuco	Araújo *et al.* 2019
Scinax cuspidatus	Parque Estadual Serra da Tiririca	145	Niterói, Rio de Janeiro	Sabagh and Rocha 2014
Scinax pachycrus	Alto da Buchada	200	São Lourenço da Mata, Pernambuco	Araújo *et al.* 2019
Scinax x-signatus	Alto da Buchada	200	São Lourenço da Mata, Pernambuco	Araújo *et al.* 2019
Sphaenorhynchus aff. *surdus*	Parque Estadual de Itapeva	33	Torres, Rio Grande do Sul	Colombo *et al.* 2008
Xenohyla truncata	Barra de Maricá	6	Rio de Janeiro, Rio de Janeiro	Lopez *et al.* 1999

or eggs at either site. This record suggests that *S. crospedospilus* is not an obligate bromeliad species (bromelicolous), as observed by Sabagh and Rocha (2014) for *Scinax cuspidatus* (Lutz, 1925), as other hylid species (Araújo *et al.* 2019). *Ololygon alcatraz* reproduces and completes its life cycle in bromeliads (bromeligenous), as do *Fritziana mitus* and *Dendrophryniscus brevipollicatus* (Haddad and Prado 2005, Haddad *et al.* 2013, Menegucci *et al.* 2017). Thus, it is likely that both, bromeligenous and bromelicolous frogs are important vectors for transporting ostracods between bromeliads.

The interaction between amphibians and ostracods is considered phoresy by several authors (e.g., Seidel 1989, Lopez *et al.* 2005, Sabagh *et al.* 2011, Lantyer-Silva *et al.* 2016) or as a prey-predator relationship when tadpoles feed on ostracods (Lopez *et al.* 2002). However, the trophic network in which ostracods and amphibians are involved is complex and a variety of relationships between these taxa are known today (Ottonelo and Romano 2011). For example, ostracods are naturally found in the digestive tract of tadpoles (Sabagh *et al.* 2012) and can pass unharmed through the amphibian intestine, being eliminated through the feces (Hartmann 1985). Thus, such transport also allows the colonization of new environments (Lopez *et al.* 2002). Conversely, depending on the abundance of these ostracods, they may feed on amphibian eggs and tadpoles (Ottonelo and Romano 2011). Thus, it seems that further studies should be conducted to understand the relationship between amphibians and ostracods, as this interaction apparently is more complex than has been documented in most studies.

In summary, this is the first record of an interaction: (1) between ostracods and an insular anuran (*Ololygon alcatraz*); (2) involving toads of the family Bufonidae (*Dendrophryniscus brevipollicatus*); and (3) between the treefrog species *Scinax crospedospilus*, *Ololygon alcatraz* and *Fritziana mitus.* Last, an updated list of neotropical frogs that interact with ostracods is provided.

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Appendix I. *Vouchers for anuran species collected.*

Individuals were deposited in the following collections: Museu de Zoologia “Coleção Zoológica da UFG”, Universidade Federal de Goiás, Goiânia, Goiás state, Brazil (*Dendrophyniscus brevipollicatus:* ZUFG-AMP 14277); Coleção Zoológica de Referência, Universidade Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul state, Brazil (*Scinax crospedospilus:* ZUFMS-AMP 12522–12523); Coleção Célio Fernando Baptista Haddad, Universidade Estadual de Rio Claro, Rio Claro, São Paulo state, Brazil (*Fritziana mitus:* CCFBH-AMP 40020).